Out of "Nothing": the quantum vacuum and creation of the universe

Quantum - "How much." 1900 – energy is emitted, transmitted, and absorbed only in discrete amounts, not a continuum. Studying this phenomena over 120 years has uncovered all the weird stuff you might have heard about. Here I'm only going to touch on the most basic principle of quantum physics.

Gravity and relativity theory is classical physics -- also very important to understand what empty space is made of, but I'm omitting almost all of that.

A VIEW OF THE VACUUM

'the space occupied by a cubic metre of solid platinum is as empty as the space of stars beyond the Earth'.

A period at the end of a sentence contains 100 billion atoms of carbon. To see one of these you would need to magnify the dot to be 100 metres across.

But to see the atomic nucleus you would need that dot to be enlarged to 10,000 kilometres: as big as the Earth.

To reveal the quarks we would need to expand the dot out to the Moon, and then keep on going another twenty times more distance.

An atom is almost a perfect void: 99.9999999999999 per cent empty space.

SO VIRTUALLY THE ENTIRE UNIVERSE IS A VACUUM. -- But that vacuum is actually where everything is happening....

1. Fields and waves (classical physics)

The nucleus is the source of powerful electric fields that fill the otherwise 'empty' space within the atom.

You are suspended an atom's breadth above the atoms in your chair, due to these forces.

A field is like a contour map for weather or elevation ...[ ]

The fields within atoms are over a thousand times greater than we can achieve with technology, though they are restricted to atomic dimensions.

There is some influence throughout space caused by the presence of the electrically charged atomic nucleus. That influence remains even when all other matter has been removed.

Same with the magnetic field of the earth. Same with gravitational field of earth.

-- If remove all bodies but one -- its mass will give a gravitational field that spreads throughout space. The gravitational field from that remote body would fill all of the otherwise 'empty' region."

-- Gravity is the warping of spacetime, so spacetime is elastic, its some kind of thing filling the vacuum. [Time by itself is not real, and space by itself is not a real, but spacetime is real.]

Fields can have waves -- If an electric charge is motionless, it is surrounded with an electric field. If it is accelerated or jiggled, an 'electromagnetic wave' is transmitted through space. An electric charge some distance away will be set in motion when the wave arrives.

Just like a water wave or sound wave, the electromagnetic wave has transported energy from the source to the receiver. For example, a radio transmitter.

Magnetic fields can be created by electric currents -- electric charges in motion.

However, suppose now that you moved alongside the wire carrying the current, and at the same velocity as the flow of electric charges within it. Now you would perceive the charges to be at rest. An electric charge at rest relative to you gives rise to an electric field, so in this situation you perceive there to be an electric field whereas previously you felt magnetism.

Speed up or slow down and magnetic fields will emerge at the expense of the electric ones. What was a magnetic field in one reference frame has become an electric field in another. Whether you interpret the field as electric or magnetic depends on your own motion.

50 years before quantum physics, electric and magnetic phenomena were described by four equations. These equations revealed a whole symphony of new phenomena.

Here's how: If the electric field was oscillating, such that the directions 'uphill' and 'downhill' were interchanged N times each second, the resulting magnetic field would also oscillate at the same frequency. If you put the oscillating magnetic field into another of the equations it predicts that this would produce a pulsating electric field. Put this electric oscillation back into the original equation and you find that the sequence goes on, electric to magnetic, back and forth. The whole thing would propagate across space as a wave.

--ANIMATION #1--

The speed of this wave could be calculated to be 300,000 km each second, independent of the frequency of the oscillations. This is also the speed of light – proved light is an electromagnetic wave.

-- Visible light consists of electromagnetic waves that oscillate hundreds of millions of times each second, the distance between successive crests in intensity being in a narrow range around a millionth of a metre. What we perceive as different colours is the result of electromagnetic waves oscillating at different frequencies. This insight implied that there have to be other electromagnetic waves –[ ]

WHAT BOTHERS ME: How can an electric field have a relativistic effect on itself, since it's all in the same reference frame? Relativity = two people moving super fast relative to each other, two different reference frames, and one person's space becomes the other person's time, you get time dilation relative to the other person.

Gravity completely different –spacetime – but still fills space and gravity waves travel speed of light.

So all space is filled with two kinds of forces, from electrical or gravitational fields.

BUT EVEN if you were able to remove all matter and energy from the universe, so all fields were removed, the vacuum of space would still be full of activity, energy, and particles because of quantum effects.

2. Everything is both wave and particle

Quantum physics revealed that *everything* is both wave and particle.

Electrons stay in shells because their waves match up so they and don't cancel out. (animation)

A particle is actually a wave until you try to detect it at a particular point, and what you detect is a particle.

THINK OF IT THIS WAY - Draw lots of dots to form a wave with a fixed wavelength. Suppose I know the position precisely; then all I have is a single dot and it is impossible to know what the wavelength will be. If I have a few dots forming the beginning of the wave, then I will begin to see if the wavelength is small or large, and only after I have a complete wavelength will I be able to say with absolute certainty what its value is. However, the price of this certainty in knowing the wavelength is giving up knowledge of position to any better precision than the length of the wave.

Mathematically this is SHOWN by Fourier analysis – the representation of any curve, or even an abrupt spike, as a superposition of waves with different wavelengths. A singular spike at a precise location is equivalent to a sum over an infinite set of waves of all wavelengths.

-- ANIMATION #2 --

→ [...*Waves in what?]*

NEXT TWO TOPICS ANSWER THIS

3. Uncertainty creates virtual particles

All of quantum mechanics derives from one fundamental property of nature:

it is not possible to measure both the position and momentum of a particle precisely.

If you know the position perfectly, then you know nothing at all about its momentum, and vice versa.

A similar uncertainty applies to **time and energy**.

This uncertainty principle is inherent in the properties of all wave-like systems. It arises in quantum mechanics simply due to the matter-wave nature of all small objects. The wave-particle duality and the uncertainty principle are kind of the same thing.

NOTE This uncertainty principle applies to atoms and molecules -- and everything else, effect is just too small to detect.

Because of this --

Particles can literally materialize out of nothing, in apparent violation of energy conservation, so long as that energy is reabsorbed by other particles within a super-short time. These are called VIRTUAL PARTICLES.

Virtual particles produce measureable effects, and they are all over the place.

THINK OF IT THIS WAY: The more that the energy account is overdrawn, the sooner it must be repaid: the more you overdraw on your bank account, the sooner the bank is likely to notice; but you pay it back before being found out and everyone is satisfied.

4. Forces are the exchange of virtual particles

This ‘virtual’ violation of energy conservation plays an essential role in the transmission of forces between particles. In the quantum picture of the electromagnetic field, it is virtual photons, quantum bundles or ‘particles’ of light, that flit across space-time and transmit the forces between remote objects -- **by carrying energy and momentum from one body to the other**.

Virtual Photons are the electric force,

Virtual gluons and W and Z bosons are the attractive force of the quarks and protons of the nucleus,

all arising and passing out of nothing

The photon and gluon are massless but W&Z bosons have mass 100 times proton, making is a short range force.

THERE’S ANOTHER LEVEL TO THIS.

The virtual particles filling space actually affect all forces acting across space [WHICH ARE ALSO VIRTUAL PARTICLES themselves]. They reduce their strength, and also make them different strengths.

The nuclear force is super strong when very close inside the atom, because not affected by a lot of other virtual particles.

The strong binding forces that grip an atomic nucleus, giving it stability, are a result of the vacuum strengthening the gluons’ grip at distances of [1000th thrillionth metre] 10^{-15} m.

Were it not for the effects of the vacuum, the strengths of all these forces would probably be the same. This implies a profound unity to the forces of nature at source, and that the multitude of disparate phenomena that occur at macroscopic distances, such as our daily experiences, are controlled by the quantum vacuum within which we exist.

MOST REVEALING QUOTE – Nobel prize winning –

“studies with large particle accelerators have now led us to understand that space is more like a piece of window glass than ideal Newtonian emptiness. It is filled with 'stuff' that is normally transparent but can be made visible by hitting it sufficiently hard to knock out a part. BUT it is relativistic, not an absolute ether as was once sought. EXPLAIN ETHER. **“The modern concept of the vacuum of space, confirmed every day by experiment, is a relativistic ether. But we do not call it this because it is taboo.”** →

So again, waves in what? A field value in what?

-- There is no substance acting as a medium for waves. The so called medium must be the INSTANTANEOUS ARISING AND PASSING of virtual wave-particles within the uncertainty limits. **So it acts like a medium, but it’s not a thing, not a substance**.

This model matches with gravity as a warping of spacetime. “It is ironic that Einstein's most creative work, the general theory of relativity, should boil down to conceptualizing space as a medium when his original premise [in special relativity] was that no such medium existed [..] The word 'ether' has extremely negative connotations in theoretical physics because of its past association with opposition to relativity.” [Robert B. Laughlin]

So it’s a medium in two ways -- a medium of virtual particles interacting in an elastic spacetime.

5. The vacuum has energy

Imagine a region of vacuum, for example a cubic metre of outer space with all of the hydrogen and other particles removed. --- Having the precise information that there is no particle at each and every point implies knowing nothing about motion and hence of **energy**.

You may remove all matter and mass, but quantum uncertainty says there exists energy: **energy cannot also be zero**. To assert that there is a void, containing nothing of these, violates the uncertainty principle. There is a minimum amount known as **zero point energy**.

All volumes of whatever size are subject to fluctuations in energy. For macroscopic volumes the effect is too small to notice, but for very small volumes the energy fluctuations are big.

The **true vacuum** is the state where the amount of energy is the minimum possible; it is the state from which no more energy can be removed. This state of vacuum is called the 'ground state'.

-- You can remove all of the real particles until you reach the ground state, but the quantum fluctuations will still survive.

Not just mathematical prediction, proved experimentally, too [Casimir effect].

The zero point motion of electromagnetic fields is ever present in the vacuum. But the zero point energy of the vacuum cannot be extracted or used as power; the vacuum is as low as it gets. **Yet the effects of zero point motion can be felt by particles passing through the vacuum**.

6. Vacuum energy can create real particles

It is possible to make these virtual fluctuations real by supplying enough energy.

Example - If a photon with high energy irradiates an atom, it may ionize that atom. However, it is possible that a virtual electron and anti-electron [called a positron] are bubbling within the atom's electric field as the photon hits. In such a case the photon may eject them out of the atom, leaving the atom behind undisturbed.

This phenomenon, known as 'pair creation', can be photographed in a bubble chamber. The **two virtual particles thus become real particles**.

[NOTE Every type of particle has an anti-particle type with opposite properties. When the two meet they annihilate each other. Positrons are injected into you to make PET scans.]

7. Different vacuum energy creates a different universe

Think about ***emergent phenomena***. That's when the organization of tiny parts produce something you couldn't predict from the individual parts.

Water – most obvious. States or phases. Phase changes.

Generally, raising temperature makes complex structures melt away.

Pencil on tip – can't predict which direction it will fall. Metastable, and then ground state.

Vacuum: pencil analogy -- False vacuum is balancing, and true vacuum lying down – but many different directions, many different true vacuums.

Just as pencil can lie in any direction, there can be many different voids that **create universes with different conditions and laws of physics**.

8. The Higgs field reveals that the universe could self-destruct

Another field -- causes some particles to have mass. ---

The Higgs field pervades the vacuum and gives mass to the W and Z bosons, electrons, quarks, and other particles.

In the absence of the Higgs field, particles could never be stationary but would all travel at the speed of light.

You are looking through the Higgs field: photons do not interact with it and so move at the speed of light.

The Higgs particle is has about 150 times the mass of a hydrogen atom.

The vacuum with no Higgs field would have <u>more</u> energy; add a Higgs field to the void → the overall energy is reduced.

The mass of the Higgs particle tells us that the vacuum is <u>not a true vacuum</u>, not zero point, thus <u>metastable</u>, one day collapse into a state where <u>life can't exist</u> -- the universe's forces, particles, and structures could cease to exist as we know them (and be replaced by different ones).

[Note: Higgs field also somehow explains why matter and antimatter are not in equal amounts.]

9. Uncertainty makes dark energy

Rees: "The fact that empty space exerts a large-scale force was discovered 20 years ago. Astronomers found that the expansion of the universe was accelerating. This was a surprise. The expansion had been known for more than 50 years, but everyone expected that it would be slowing down because of the gravitational pull that galaxies and other structures exert on each other. It was therefore a big surprise to find that this deceleration due to gravity was overwhelmed by something "pushing" the expansion [starting 5 billion years ago]. There is, as it were, energy latent in empty space itself, which causes a sort of repulsion which outweighs the attraction of gravity on these large scales. This phenomenon – dubbed dark energy – is the most dramatic manifestation of the fact that empty space is not featureless and irrelevant. Indeed it determines our universe's long term fate."

The strength of the dark energy is [trillionth x10] the strength of gravity. But it makes up 68% of the total mass-energy of the observable universe.

Is it from uncertainty? *Yes.*

-- A major outstanding problem is that the same quantum field theories predict that dark energy should be huge – [trillion x8] too large.

10. Origin of the universe

The attractive force of gravity pervades the cosmos with negative potential energy for everything trapped within it.

This negative energy cancels out all the mc^2 energy of matter → the total energy of the universe is near to nothing.

It turns out that the universe is a huge vacuum fluctuation where the total energy is so near to zero that it can exist for a very long time before the vacuum accountant demands that the books are balanced.

If the total energy is exactly zero, it could last forever.

HERE'S HOW WE KNOW ABOUT THE BIG BANG ["From the observed rate of expansion of the universe and knowledge of its background temperature now, we can calculate back and estimate its temperature at various epochs in the past. It gets ever hotter as we approach nearer to the singular event that we call the Big Bang. Collisions among particles would have been much more violent then, so much so that at temperatures greater than 4,000° atoms would be unable to survive; they would have been ionized as they are within the hot Sun today. At temperatures above a billion degrees even atomic nuclei are disrupted; a plasma of particles and radiation is all that would have existed in those first moments. Prior to this, the energy would have been enough for particles of matter and antimatter to have emerged. All the evidence implies that our material universe came from a vacuum of hot radiation.]

["Experiments at particle accelerators, such as at CERN, show how matter particles and forces behave at high energy and, by implication, at extreme temperatures. **This enables us to calculate how the universe behaves all the way back to temperatures of [trillion trillion] 10^{27} degrees,** which corresponds to **times within [a trillionth trillionth trillionth second]** [10^{-33} seconds] of the Big Bang. --

-- At various temperatures the vacuum undergoes phase transitions."]

So the cooling freezes out **one kind** of emergent structure. This means:

"the pattern of particles and forces that we are governed by may be r**andomly frozen accidental remnants of a phase change when the universe 'froze' at a temperature of about 10-trillion [10^{17}] degrees**. We are like the roulette wheel where the ball landed in the slot that enabled life to arise. Had the ball landed elsewhere, such that the mass of the electron [or strength of gravity or amount of

dark matter were different], then we would have been losers in the lottery and life would not have occurred."

For example - Universes with higher density would quickly collapse back again by gravity.

Many other universes separate from ours have probably been created this way, with different initial conditions and different laws of physics → HERE'S WHY

11. Inflation and the multiverse

IN THE FIRST INSTANT THERE WAS AN INCREDIBLE INFLATION -- inflation is similar to dark energy, but –

HIGH PRESSURE → GRAVITY WAS REPULSIVE.

-- universe doubled in size every [trillionth x4] $\mathbf{10^{-38}}$ second!

The energy of this antigravity created much more mass so that the inflating volume didn't dilute.

This might have all been because of a transition from a false vacuum to the Higgs vacuum.

SIZE of the initial vacuum fluctuation was [trillionth x4 metre] 10^{-52} m, much smaller than an atom, START OF INFLATION and the next instant, when inflation stopped, our starting Hot Big Bang was size of **orange, with the mass of the whole universe**.

THEN AFTER ONE SECOND THE UNIVERSE WAS ALMOST AS BIG AS IT IS NOW.

So our Hot Big Bang happened *after* the initial instant of inflation – **cold swoosh**.

So our Big Bang was *not* the beginning of time.

Inflation cannot stop. –PAPER FIGURE --

Likely size a thousand times larger.

* Each bubble/pocket can be infinite on inside while small on outside.

Inflation erases all evidence of what happened before our hot big bang.

Epilogue

Many Worlds + time not a dimension

Mathematical structures = reality

--Physics is only relational. Properties without parts / substance.

Niels Bohr: *"Everything we call real is made of things that cannot be regarded as real."*

--Thus property dualism of consiousness is as physical as anything else.

--Computable mathematical structure, so this is a TOE because doesn't require initial conditions.

Q: Implies existence of space and time to begin with – so why spacetime, logic, causality, math, uncertainty, quantization?

A: This is the only kind of multiverse that could spontaneously arise? Meaning: God is a switch, one bit.

"How much of science is going to be accessible to the human brain? ... We may have to await the emergence of some kind of post-humans to get a fuller understanding." Martin Rees

"In the beginning the Universe was created. This has made a lot of people very angry and been widely regarded as a bad move." – Douglas Adams

Energy = force x distance

- Total energy is always the same (“conserved”);
- it just converts between kinetic and potential energy.

Momentum = mass x velocity (has direction)

Spacetime: 3 dimensions of space + time as a 4th dimension

Atom = electrons + quarks (in nucleus; protons & neutrons) [these are all *particles*]

Photon: a particle of light

Billion: 1,000,000,000 (9 zeros)

Trillion: 1,000,000,000,000 (thousand billion, 12 zeros)